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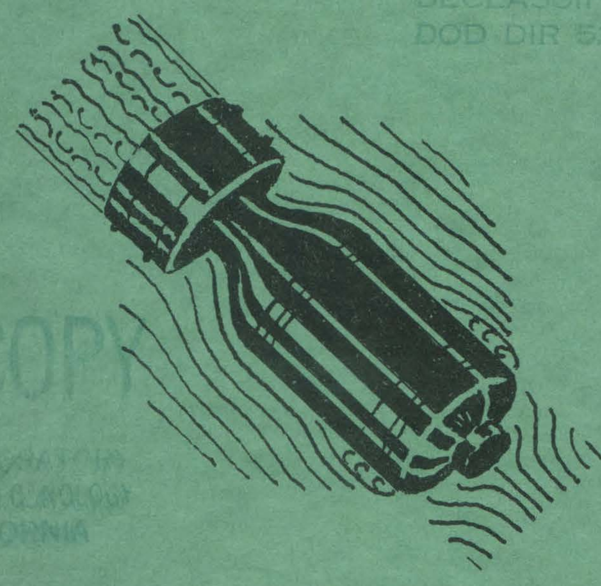
TESTS OF THE AN-MARK 53 AIRCRAFT DEPTH BOMB



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY.
PASADENA, CALIFORNIA

SECTION № 6.1 - sr 207-2350

LABORATORY № ND-44

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TESTS OF THE

AN-MARK 53 AIRCRAFT DEPTH BOMB

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THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRODYNAMICS LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr207-2350

Laboratory No. ND-44

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August 31, 1945

TESTS OF THE

MK 53 AIRCRAFT DEPTH BOMB

This report covers Water Tunnel tests made on a 2-inch diameter model of the Mk 53 Aircraft Depth Bomb. These tests were conducted at the Hydrodynamics Laboratory of the California Institute of Technology and were authorized by Dr. L. G. Straub, Head Technical Aide to Section 6.1, National Defense Research Committee, in a letter dated July 12, 1945.

This work included cavitation photographs of the model in the Water Tunnel under a wide range of values for the cavitation parameter, tests to determine the moment, drag, and cross force coefficients, and also tests to obtain the pressure distribution along the afterbody and the hydrostatic fuze located within the tail structure. The model was also provided with pressure taps at the nose and forward part of the body, but the pressure distribution for these taps was not determined on account of lack of time.

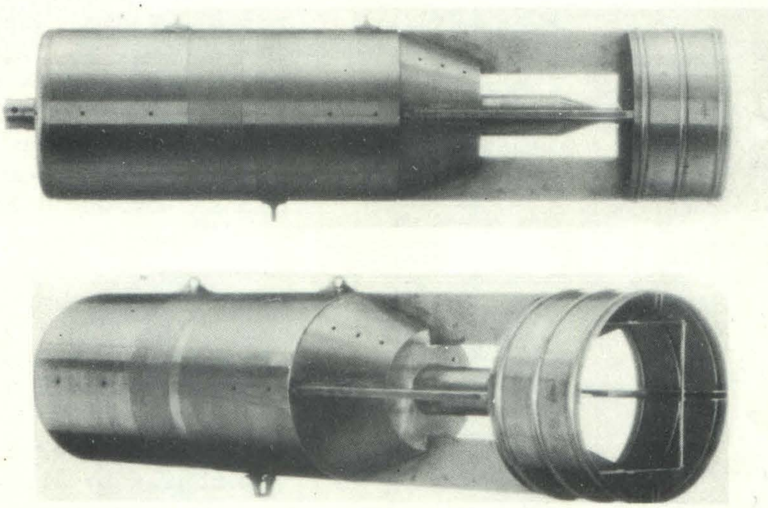

FIG. 1 – PHOTOGRAPHS OF THE MODEL

DESCRIPTION OF PROJECTILE

This projectile has a very blunt conical nose, a short body, and a ring tail supported on four fins. It is very similar to the Mk 41 Depth Bomb, but of a more compact design. The bomb is equipped with a contact fuze in the nose and a hydrostatic depth fuze within the tail. Figure 1 gives two views of the model. The following physical data apply to this projectile:

Body diameter	13.50 inches
Overall length	54.16 inches
Ring tail length	7.25 inches
Face of nose fuze to C.G.	20.29 inches
Total Loaded weight	323.8 pounds

PERFORMANCE CHARACTERISTICS

The force and moment coefficient* curves for this projectile are shown in Figure 2. The cross force coefficient is practically a linear function of the yaw angle being about 0.047 per degree of yaw. The drag coefficient is 0.42 at zero yaw increasing to 0.63 at a yaw angle of 10 degrees, this high drag being characteristic of such blunt-nosed bodies. The yawing plane for all tests passed through the supporting lugs and contained two of the four fins. It is to be noted that the force and moment coefficients for yaws in other planes would differ slightly from those shown in Figure 3.

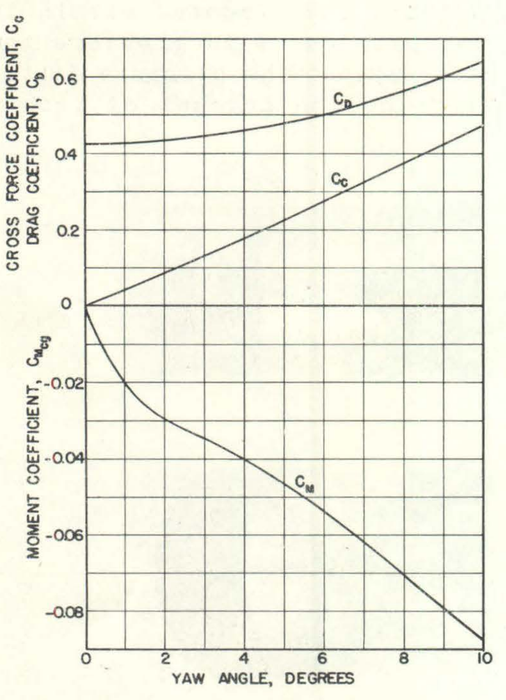

FIG. 2 – DRAG, CROSS FORCE, AND MOMENT COEFFICIENTS

The bomb is stable throughout the range of yaw angles tested. There is a rapid increase in stabilizing moment coefficient for yaw angles between 0 degrees and 1.5 degrees, the increase being about 0.02 per degree of yaw. Above 2-degrees yaw, the increase in moment coefficient is approximately 0.007 per degree of yaw.

*The coefficients and other symbols used in this report are defined in the appendix.

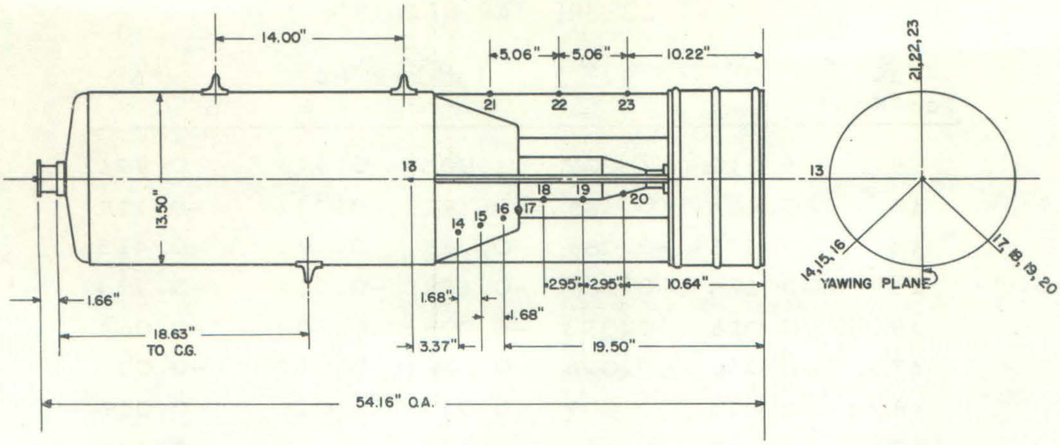

FIG. 3 — OUTLINE OF PROJECTILE WITH LOCATION OF PRESSURE TAPS

PRESSURE DISTRIBUTION

Pressure distribution tests were made in order to determine the most desirable point at which to supply pressure to the hydrostatic depth fuze in the tail. The model was provided with pressure taps throughout its length, but the pressure distribution tests completed at this time were confined to those in the afterbody and tail structure. The pressure tests for the nose and forward part of the body can be made at a later date if desired.

Figure 3 shows the location of the pressure taps for the aft part of the model, five taps (Nos. 13 to 17) were on the afterbody, three taps (Nos. 18, 19, 20) were on the hydrostatic fuze, three (Nos. 21, 22, 23) were on the outside of one of the fins, and No. 1 was in the center of the nose. The end view of the model at the right of Figure 3 shows the orientation of the pressure taps with reference to the yawing plane. This orientation was kept the same for all tests. Pressures, above and below the static gage pressure of 25 pounds per square inch, were measured with a differential pressure gage at a water velocity of 40 feet per second and for yaw angles of 0, +3, -3, +6, and -6 degrees. These pressures were corrected for pressure drop in the tunnel working section.

The following table gives the readings at the various pressure taps expressed as a decimal fraction of the velocity head above or below static pressure.

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PRESSURE TAP READINGS

Yaw / Tap No.	0°	-3°	+3°	-6°	+6°
1	1.010	1.007	1.003	0.993	0.991
13	-0.164	-0.188	-0.195	-0.232	-0.228
14	-0.375	-0.288	-0.388	-0.292	-0.413
15	-0.195	-0.166	-0.171	-0.084	-0.234
16	-0.056	-0.053	-0.036	-0.000	-0.064
17	-0.038	-0.006	-0.009	-0.033	-0.015
18	0.024	0.009	0.020	0.025	0.019
19	0.159	0.117	0.139	0.116	0.131
20	0.094	0.075	0.090	0.098	0.087
21	-0.059	-0.024	-0.031	-0.012	-0.011
22	0.015	0.040	0.029	0.053	0.035
23	0.078	0.107	0.079	0.119	0.073

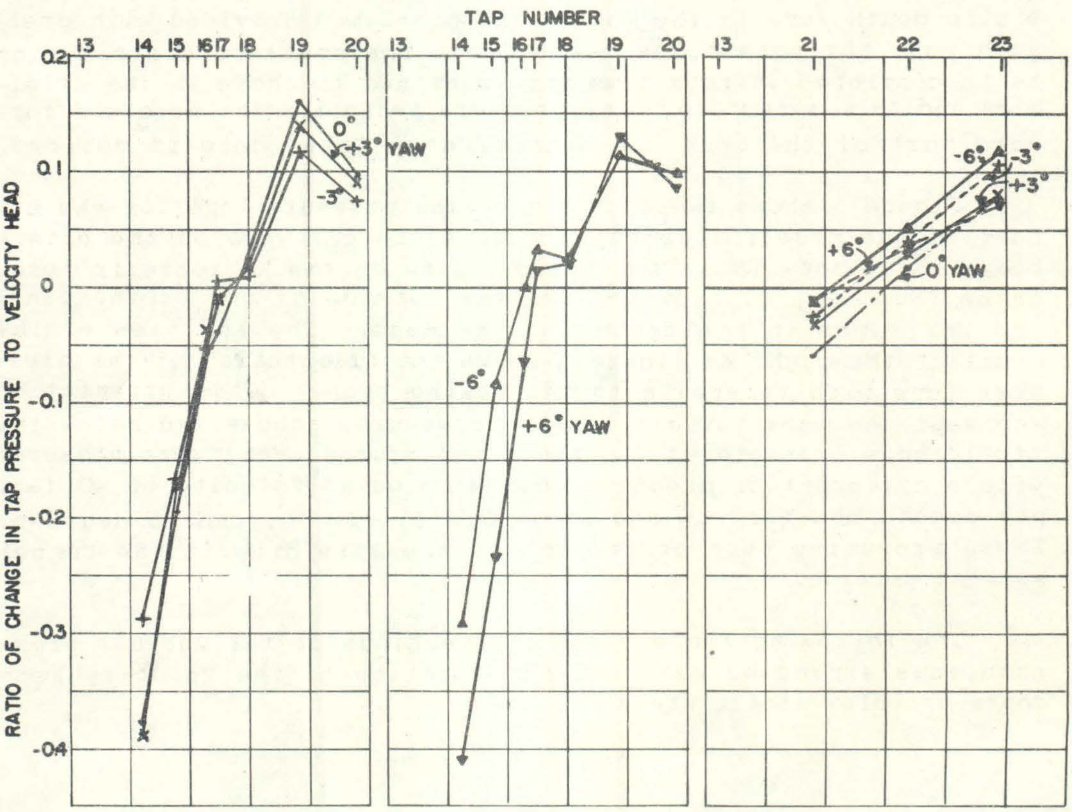

FIG. 4 – CURVES OF PRESSURE DISTRIBUTION

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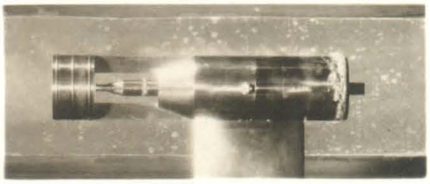
In Figure 4 these pressure readings are plotted in various combinations. In (a) is shown the pressures for Taps 13 to 20, at yaw angles of 0, -3, and +3 degrees. In (b) is shown the pressures for the same taps at yaw angles of -6 and +6 degrees. In (c) are the pressures for Taps 13, 21, 22, and 23 which are all on the outside diameter of the projectile. These curves should make it possible to determine the proper position of the pressure tap for the hydrostatic fuze. Should it be desired to supply to the fuze a pressure equal to the static pressure corresponding to the depth of the bomb, it is seen that Taps 16 or 17 should be satisfactory. It would also be possible to select a similar point between Taps 21 and 22 on the outer edge of the fin. These curves will also show where the fuze tap should be located to obtain a pressure above or below static. On account of symmetry of flow and also the symmetry of the model, the pressures at Taps 14 to 20, inclusive, can properly be considered as being taken along a meridian.

CAVITATION TESTS

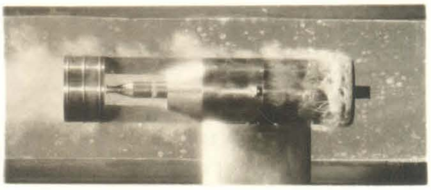
Tests were made on the model to determine the cavitation effects for various values of the cavitation parameter, K. The model was first carefully observed for the points of steady incipient cavitation which cannot be photographed.

Incipient cavitation at zero yaw for values of K of 2.0 or over were observed on the outside rounded edge of the nose and at the aft edges of the lifting lugs. At a K of 1.34 steady incipient cavitation occurred on the conical end of the afterbody at about the position of Tap 14. At a yaw angle of 5 degrees, incipient cavitation occurred in the nose and lugs at a somewhat higher value of K, but there was little change around the afterbody and tail.

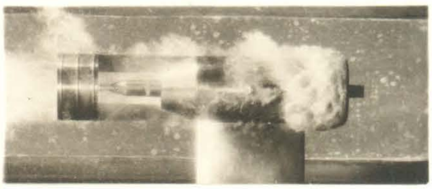
The photographs in Figure 5 show the cavitation bubbles for 0 and 5 degrees yaw for K's from 2.04 to 0.86. These photographs indicate that the principal cavitation effects are confined to the nose and there should be no cavitation that would seriously affect a fuze pressure tap located on the conical afterbody or on the fuze itself.



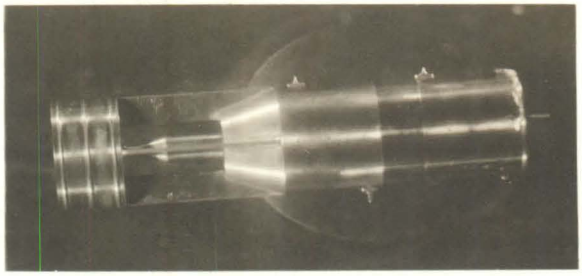
(A) K = 1.93
ψ = 0°



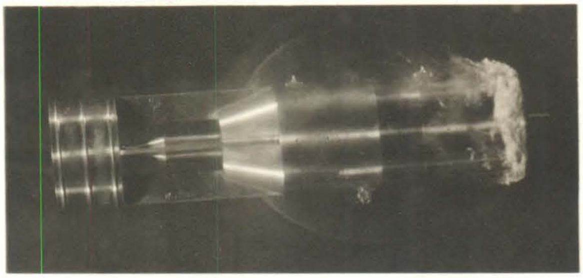
(B) K = 1.29
ψ = 0°



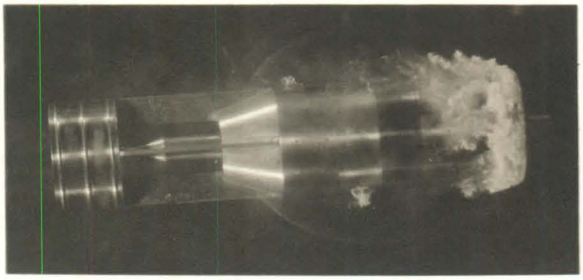
(C) K = 0.93
ψ = 0°



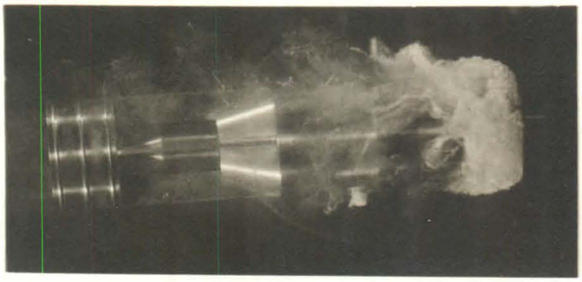
(D)
K = 2.04
ψ = 5°



(E)
K = 1.63
ψ = 5°



(F)
K = 1.31
ψ = 5°



(G)
K = 1.07
ψ = 5°

(H)
K = 0.86
ψ = 5°

FIG. 5 — CAVITATION PHOTOGRAPHS

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (−).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (−) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (−) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (−). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (−).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or pitch angle, and a stabilizing effect when the moment and yaw or pitch angle have opposite signs

NORMAL COMPONENT, N

The sum of the components of the drag and cross force (or lift) acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \tag{1}$$

or

$$N = D \sin \alpha + L \cos \alpha \tag{1a}$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

L = Lift force in lbs

ψ = Yaw angle in degrees

α = Pitch angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \tag{2}$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \tag{3}$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \tag{4}$$

Lift coefficient, $$C_L = \frac{L}{\rho \frac{V^2}{2} A_D} \tag{5}$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \tag{6}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

L = Measured lift force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \qquad (7)$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{p_L - p_B}{\rho \frac{V^2}{2}} \qquad (8)$$

in which

K = Cavitation parameter

p_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

p_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \qquad (9)$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The cavitation parameter for incipient cavitation has the symbol K_i.

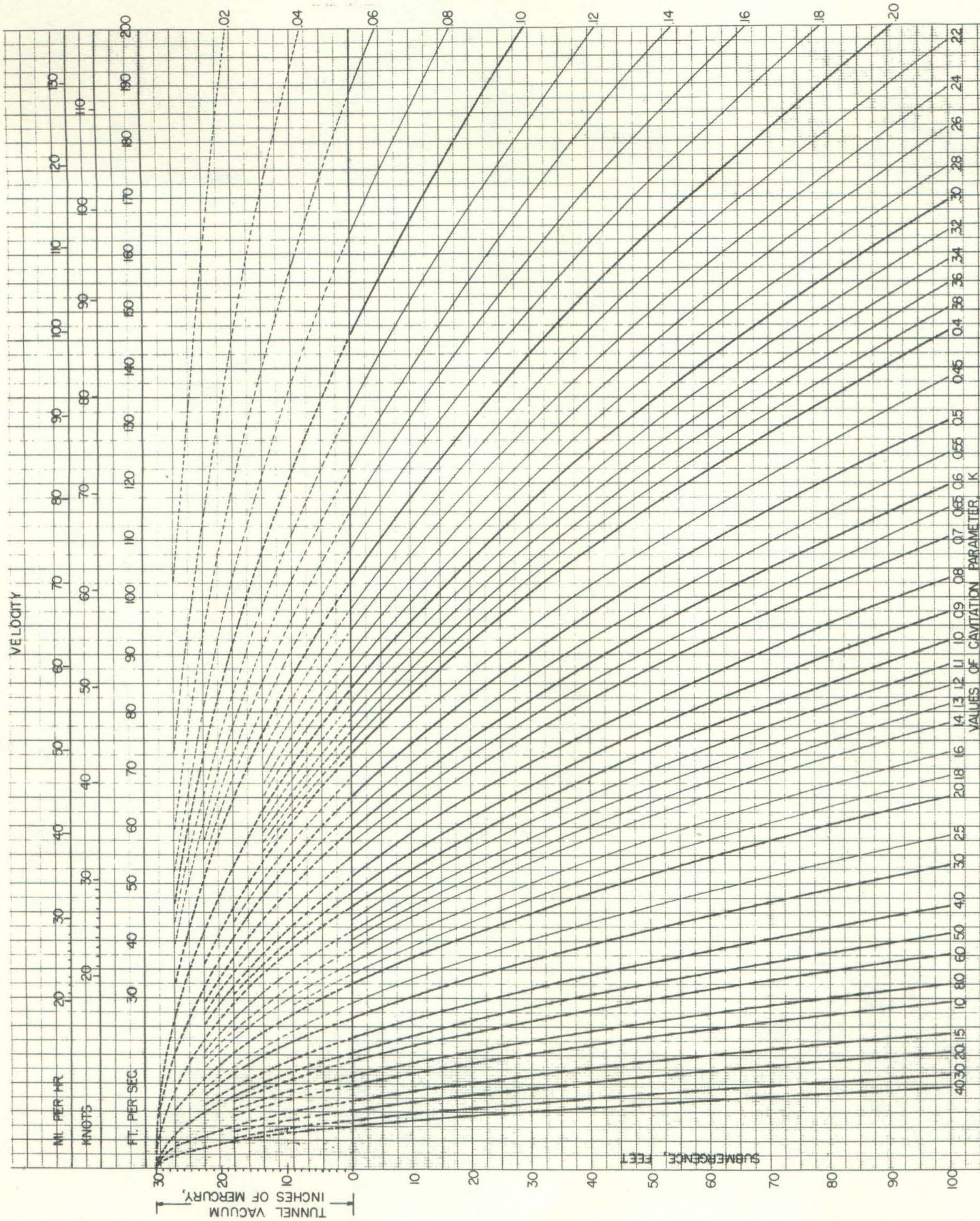
The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing amplitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability or instability can be obtained from the center of pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.



NOTE: VALUES FOR K ARE FOR ZERO BUBBLE PRESSURE. TO OBTAIN TRUE VALUE OF K SUBTRACT BUBBLE PRESSURE, IN FEET, FROM THE SUBMERGENCE. CHART IS CALCULATED FOR SEA WATER.

CHART SHOWING RELATION BETWEEN VELOCITY, SUBMERGENCE & CAVITATION PARAMETER